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Is physics different from biology?

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ABSTRACT: It is generally assumed that physics and chemistry are more 'exact' than biology, the reason being that these sciences, notably physics, allow for predictions that can be confirmed experimentally. However, once it became possible, with the development of quantum physics, to observe the single particles, it turned out that we cannot predict their behaviour. This was a great concern to many physicists , but in fact , it only shows that as far as prediction is concerned physics is on a par with all the other empirical sciences. The reason for the exactness of physics is that one observes millards of 'individuals' at one time, and then the deviation of single particles cannot be observed. Thus, the laws of physics are just as much probalistic as those of the other sciences, implying that they are not absolutely, but only statistically true. In biology we are rarely able to work with more than a limitated number of individuals, and therefore predictions are doomed to fail from time to time. But we are surely able to make predictions which are almost as precise as the physical ones. Thus, for instance: All humans have two legs. We all know, and may even have observed, exceptions to this generalization, but they are statistically insignificant.

«To state quite clearly why one particular bubble lives to ripe old age, while another is struck by a falling drop and killed instantly, we would have to trace the patterns of puddle, sky, and weather so completely as to know the disposition of every last molecule. And, even then, we would still be unable to predict every gesture of the agitated pool because the courses of chaos are by definition undefinable.»

Jonathan Weiner (1984)

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1. LEVELS OF ORGANIZATION

Among the natural sciences physics –and to a lesser extent chemistry– are often regarded to be more «exact» than the disciplines located at the higher levels of organization, biology, ethology and ecology. The reason for this distinction is that the scientists engaged in the study of physics and chemistry have been able to formulate a great number of generalizations –theories– which permit to predict future observations with a great, if varying precision. These theories, often called «laws», are of widely differing generality; among the most comprehensive we may mention Newton's laws, the periodic system and the laws of thermodynamics.

In biology the situation is complicated by the fact that this branch of science may be studied at many levels of organization, including those of physics and chemistry. The phenomena studied by biophysicists and biochemists –including molecular biologists– differ in many respects from those of physics and chemistry, but, as might be expected, most of the laws valid in the latter disciplines also hold for biological processes. If, as implied by the present heading, we want to compare physics and biology, it is therefore necessary to consider in particular biological phenomena occurring at the organismic level. The question facing us is therefore: Is there any fundamental epistemological difference between the pursuits of physicists and biologists? This question has been discussed by RUSE (1977), who came to the conclusion that, apart from the fact that biology does not, so far at least, contain any non-statistical laws like Newtonian mechanics, the two disciplines rest on the same epistemological foundation.

To a very large extent I am inclined to agree with Ruse, but some very important reservations are needed. First of all, in my opinion the vast majority of physical laws are statistical, Newtonian mechanics is a, or perhaps the exception. Second, in his argumentation for the existence of hypothetico-deductive laws in biology Ruse opted for Mendelian population genetics. If this theory had been chosen to exemplify a law of inheritance, no objection could be raised, but unfortunately it was presented as a theory of biological evolution, and as such I believe it has insurmountable shortcomings.

I shall try to vindicate my views **in** the following discussion, where I compare the epistemological standing of physical and biological theories. The comparison will be made on three levels of aggregation: units, small aggregations and large aggregations.

2. UNITS

Disregarding elementary particles, the individual entities in physics are atoms and molecules. Without being a specialist I venture to assert that there are no hypothetico-deductive laws in physics which permit to predict in detail the fate of individual atoms and molecules.

When we ascend the hierarchy of organization and enter the realm of chemistry, the units, the molecules, increase in size; this reduces the uncertainty with respect to parameters like location and velocity, but at the same time the number of possible variations is raised. Thus, for instance, biological molecules are so large that individual exemplars can be visualized, and yet, even if a certain macromolecule has been isolated from a population of known chemical composition, we cannot be sure that this particular specimen conforms with the established formula. In fact, this uncertainty constitutes the basis of biological evolution, for if macromolecules could be reproduced with absolute fidelity, no mutations would ever have occurred, and hence evolutionary innovation would have been barred. In biology the unit is an organism. Among the higher animals and plants the variation is so great that individuals are often easily distinguishable by form, pattern, size of behaviour. In most instances living organisms may trace their origin back to a zygote, a single cell, which does not allow for the kind of individual differences which occur in adults. Presuming a causal relation between the differences obtaining in the zygote and those present in the later ontogenetic stages, the initial differences must have been found at a level of organization below that of the cell. This inference is roundly corroborated by current knowledge; we know that a large part of the observed individual differences may be referred to variations in the DNA molecules which constitute the genome. This translation of differences from lower to higher levels of organization may probably be subsumed under the concept of «epigenetic amplification» (LØVTRUP, 1974). The conclusion of the present section is thus that on the level of aggregation represented by individuals there is no difference between physics and biology; in neither case is it possible to establish hypothetico-deductive generalizations, laws which allow for predictions concerning the fate or properties of individual entities.

3. SMALL AGGREGATIONS

The «smallness» of the aggregations dealt with in the present section depends upon two characteristics. First, the extension of the aggregations

must be small enough to make them surveyable, thus termination of all relevant parameters. Second, the number of units must be so large that it is possible to obtain statistically significant evaluations. Evidently, these two requirements are easily met with in physical and chemical systems, but in biology this situation is relatively exceptional.

All the hypothetico-deductive laws of physics, whether referring to gases, fluids or solids, owe their validity to the circumstance that in any realizable situation myriads of units are involved. Even in the solid state, representing the highest degree of order, the predictions deduced from the laws do not refer to individual atoms or ions, but to the compound aggregation. It is a typical feature of chemical laws that the more their subject approaches physics –the greater is the exactness with which they can be formulated. As regards the outcome of large scale reactions, the predictive accomplishments of the prevailing chemical laws are hardly more than moderately successful.

The existence of living organisms depends upon physical and chemical processes. These can be demonstrated and studied experimentally in living organisms, or in isolated parts representing many levels of organization. In some instances we are dealing with small aggregations of ions, atoms or molecules, which behave as predicted by the physical and chemical laws, approximately at least.

One group of living organisms allows for the establishment of small aggregations in which the number of units is so large that we have a situation comparable to that obtaining in physics and chemistry. The beings in question are the microorganisms, particularly the bacteria, some of which, when cultured, behave as predictably many chemicals. This is the prime reason for the favour which, say, *E. coli* enjoys among molecular biologists. However, the bacteria represent the lowest level of organization in the realm of life, so in spite of the enormous contribution to human knowledge afforded by studies on microorganism, it must be acknowledged that there are many biological problems to which they can yield no answer.

The number of biological units which can be surveyed in one sample will of course diminish with the size of the individuals. If we choose our examples among typical experimental organisms, then it will be found that with *Drosophila*, the fruit fly, it may be possible to make experiments with aggregations comprising several thousand individuals, but with laboratory rats and guinea pigs it will probably be necessary to reduce the number by at least one order of magnitude. Needless to say, with still larger animals the numbers must be further decreased. It is therefore quite obvious

that when working with biological problems we shall very soon reach the situation where the number of units in the aggregations no longer allows for statistically significant predictions.
To illustrate my point I shall make the following quotation:

> Consider the generalization that cows have four legs. This does not mean that all cows have four legs. There is no reason why a freak calf should not be born with three or five legs. So the generalization that cows have four legs is not meant seriously to exclude the suggestion that some cows do not have four legs (Smart, 1968, p. 94).

Before I comment upon this statement let me first observe that as a biologist I believe that five legs, if possible at all, will be much rarer than three legs. Be this as it may, if we were to survery a million, or even a billion cows at one occasion we would hardly be able to notice some exceptional three-legged individuals. But even if we did, we should still be able to corroborate with comfortable statistical significance the «law»: All cows have four legs. In other words, if the sample, the biological aggregation, is large enough, then the biological «generalizations» will be as valid as any physical law. In this regard there is thus no fundamental difference between physical and biological laws.
SMART (1968, pp. 94 and 43) considers

> that there may be no laws about organisms but only exception-ridden generalizations (which are) terrestrially applicable... rather than... universal laws of nature.

Having already disposed of the first charge, we must now consider the second one, the domain of validity. It is a basic tenet that science, in contrast to metaphysics, shall deal with phenomena which are directly or indirectly observable. It so happens we can observe a lot of events going on in the universe, all of which concern matter organized at the physical, and to a modest extent at the chemical level of organization. This circumstance has confirmed that the theories established for these levels of organization on our planet are valid also in the universe; so far these theories are therefore universal.
On the earth a process of evolution has led to the organization of matter at levels far above those which we can observe in space. It is possible that a corresponding rise in organization has taken place elsewhere in the universe, even to the extent that self-reproducing entities have come into existence. It seems unlikely, however, that such a process has followed same course as on our planet. We must therefore admit that biological

theories, for all we know, are valid only on our own planet. As shown by the above quotation, some philosophers of science find this to be a great shortcoming, but I fail to see why; what difference would it make if we knew for certain that the fundamental laws of life are the same everywhere in the universe? This knowledge would not permit us to make any testable predictions, and hence it would remain on the wrong side of the line of demarkation between metaphysics and empirical knowledge.

The physical and chemical theories are distinguished by being couched in mathematical terms, and they therefore allow for the direct calculation of their predictions. If the stand adopted here is correct, then it also ought to be possible to formulate biological theories mathematically. However, to achieve this goal it would be necessary to focus on single or some few of the many properties exhibited by living organisms, and furthermore to work with systems where a reasonably large number of units are involved. The only well-known example where these demands are met with is the Mendelian theory of heredity. The appearance of exactness which the mathematical formulation has conveyed upon this theory, may to a large extent explain the popularity it enjoys among present-day biologists.

There are other situations in biology where it is possible to make predictions. Suppose that a systematist states the specific name of a certain organism. In this case a specialist will immediately be able to list a variety of characteristics, distinguishing the sequence of subordinate taxa to which the organism belongs. If the species has not been described previously, the specific characters may not be predicted, if it has, there will still be a number of features that are unpredictable, for in living organisms individual variations always obtain. To be sure, in the lowest ranks of organization it may be difficult to demonstrate such differences, but the possibilities of variation are so many that we have little reason to believe that any two individuals are ever completely identical. In a majority of instances predictions of this kind will come true, particularly those relating to the superior taxa. But exceptions will occur, and it may therefore be necessary to repeat the procedure in order to obtain a statistically significant result. But if this rule is followed then biological theories will be as significant statistically as those of physics and chemistry.

4. LARGE AGGREGATIONS

Aggregations which comprise so many units that they no longer are surveyable, are said to be «large». Whereas small aggregations often may contain units of a single kind, this situation probably never arises in large aggregates.

NOTE: The sections in blue were translated from the Italian version of this essay in the same volume of the journal (pages 456, 457 and 458), to fill in the missing pages in English that could not be found.

In these circumstances, the possibilities for interactions are so many and so varied that prediction is no longer possible.
In the physical world, geological and meteorological phenomena belong to this class; it may be noted that in both cases the spatial extent can be vast.
In biology, large aggregates are well exemplified by *ecological systems*, often composed of innumerable elements, including some inorganic ones. Even a superficial acquaintance with the state of nature is enough to realise that it is impossible to predict the fate of individual organisms in such systems. In this case, the large number of units is of no help because, in contrast to the situation in small aggregates, the units differ from one another, sometimes blatantly, sometimes imperceptibly.
The currently accepted theory of evolution, which goes under names such as neo-Darwinism, synthetic theory or neo-Mendelism, deals with the statistical distribution of genes already prevalent in successive generations, and is thus related to the survival of individuals representing various genomes. However, the process of evolution involves two phenomena, firstly the *creation* of evolutionary innovations, and secondly their *survival*. The creative aspect can be associated more or less directly with mutations in the genome, and will involve processes within the organism, at more or less modest levels of organisation. The effect of mutations will manifest itself during ontogeny and it may therefore be possible to ascertain their mode of action with epigenetic studies.
Thus, as long as we limit ourselves to current organisms, there will be no great difficulty in explaining the creative aspects of evolution, and this may allow us to 'predict' the mutations that in the past have ensured the evolutionary transition from one large taxon to another. But, of course, since mutations are random events, we cannot predict anything about what will happen in the future. Returning to the problem of survival, it is possible to make certain predictions about the future frequency of certain genomes in small clusters, based on the fact that the probability of survival under certain tightly controlled experimental conditions such as we have, say, in a drosophila cage, is correlated with the presence-absence of a certain gene.

The modern theory of evolution is an extrapolation from the situation of these small aggregates to the large aggregate state in nature. Since extrapolation from small to large aggregates is not permissible, we can once again deduce that nothing can be predicted about future evolutionary events. Some philosophers of science have criticised the current theory of evolution because it cannot make predictions about the future. This is clearly a mistake, firstly because predicting the future is impossible, and secondly because evolutionists are concerned with the past history of evolution and not the future. It will be objected, however, that past evolution is a unique historical event, and unique events do not allow for generalisations. This is true, but with some important reservations. In human history all protagonists are unique; they may have left successors, but only exceptionally did the latter walk in their parents' shoes. In biology it is very different, because here survival implies reproduction. Consequently, the outcome of certain creative events will be multiplied and preserved in future generations, a phenomenon that can perhaps be called 'ecological amplification'.

As we have seen, this circumstance allows us to study the material basis of past evolutionary events. But the historical case for evolution can also be known. For if we study the distribution of characters in living organisms, we can classify them in such a way as to describe the temporal sequence in which the various characters appeared, and such a phylogenetic classification corresponds to a record of the history of evolution.

However, one should not expect to always be able to make unequivocal classifications. Both creation and survival are subject to chance. But again, if we can work on so many characters that our material constitutes a small aggregate, we can expect statistically significant results. It can be observed that this attempt to delineate a historical process implies predictions, not of the future, but of future observations.

5. CONCLUSION

The present article touches on the problem of determinism. I am not competent to discuss the subject in detail, but I am inclined to agree with the author of the epigraph whose opinion can be summarized in the assertion that prediction of the future requires omniscience. And since there are no omniscients among men, we cannot predict the future. It may seem that this conclusion contradicts the experimental method and the hypothetico-deductive attitude, according to which one of the first purposes of research

is to be able to predict future events. As we have seen, one objection to the prevailing theory of evolution is that it does not allow for any predictions. However, the notion that «prediction» should imply future events only shows how much Newtonian physics still influences the scientific mind. For the circumstance that prediction is possible in this case stems from the fact that some few, relatively large bodies move in a space that is empty to all intents and purposes. If there were a hundred times as many planets, or if the density of matter in space were increased a billion-fold, then I do not think that the laws of Newton would have been equally successful with respect to their predictive power. The reason why Newtonian mechanics is non-statistical is that there are only a few individuals and very little interaction.

As far as matters on our planet are concerned the question about predictability is much less clear than the philosophical discussion seems to imply. In fact, it is only under very narrow and specified conditions that we are able to make any predictions. These conditions were denoted by the word «small aggregations». The main properties of these are that they are large enough, i.e. comprise a sufficient number of individuals, to permit statistical analysis, and small enough to be surveyable. And these requirements hold for physical as well as for biological events, and therefore it is wrong to compare the possible antagonism between physics and biology with the antagonism between nonstatistical and statistical theories. All the laws of nature are generalizations based on observations made, not on unitary elements, but on aggregations, and we can never expect them to hold for the single units. So whether physical or biological, all natural laws are statistical, and we may therefore agree with Ruse that there is no principal difference between physics and biology, even if this conclusion is arrived at from a standpoint opposed to that of his.

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